11. INNOVATIVE LOCK DESIGN

Settlement and development of the interior of the United States was initially by way of the Ohio and Mississippi River, and the earliest navigation developments were on those rivers. The first Federal public works program was clearing and snagging for navigation on the Ohio River in 1842, and the first navigation lock and dam was constructed on the Ohio River, about five miles below Pittsburgh, in 1885. It was very successful and led to construction of other navigation works on the Upper Mississippi, Ohio, and tributaries, Figure 11.1.

By 1929, 981 miles of the Ohio River had been canalized by 52 locks and dams to provide a 9-ft channel. Later the original 52 structures were replaced with 20 higher lift locks and non-navigable dams, Figure 11.2. Also there are 51 locks and dams on Ohio River tributaries. Total length of the Ohio system is 2776 miles. The standard tow has 15 barges (3 wide, 5 long) and a towboat.

By 1940, 850 miles of the Upper Mississippi River had been canalized by 26 locks (110- by 600-ft) and dams. Later larger locks were constructed at some locations; a lateral canal with two locks was constructed near St. Louis; and navigation was extended 4.6 miles upstream at Minneapolis by construction of two smaller locks at St. Anthony Falls. The system now has 29 locks, Figure 11.3. The Upper Mississippi and tributaries now provide 1982 miles of navigable waterway. The standard tow is the same as on the Ohio River.

11.1 Need for Rehabilitation or Replacement of Navigation Structures

Annual waterborne tonnage on the Ohio River increased from 22 million tons in 1930 to 151 million tons in 1982. On the Upper Mississippi, tonnage increased from 3.1 million tons in 1940 to 91 million tons in 1982, Figure 11.4.

Advances in towing equipment over the years, including towboats with increased engine horsepower, have allowed larger and heavier tows to be moved and have extended navigation to periods of relatively high flows and moderate ice conditions.

Modern tows are larger than the tows for which the locks and lock approaches were designed. This, combined with higher entrance velocities at the locks during high flows, has created navigation problems at the older locks. The longer tows require double lockage, and operators must use extreme care in entering the locks. For example, lockage at the small old Gallipolis Locks on the Ohio River required multiple lockages and as much as 4.5 hours to lock through a single tow, while tows pass through the 1200-ft locks on the Ohio in about an hour. Such delays are costly for shippers. In 1992 delays of tows at five of the locks and dams on the Upper Mississippi totaled 87,000 hours, representing an estimated loss to shippers of $35 million.

When navigation projects on the Ohio and Upper Mississippi Rivers were designed and constructed, projections of future traffic were much lower than what has actually occurred. Thus, the locks have been more heavily used than foreseen, and expensive and frequent maintenance has been needed. However, budget constraints have limited maintenance work, and many of the older structures have deteriorated.

There is need for a systematic, effective, and adequately funded maintenance program for waterway systems to remain useful and efficient. While routine maintenance is generally all that is required in the early years of project operation, unforeseen construction may be needed later to enhance operation or correct deficiencies. It is important to perform maintenance as needed, before problems become major and require closure of the waterway for major repairs.

Traffic from both the Upper Mississippi River and the Illinois Waterway passed through the old Lock and Dam 26, on the Upper Mississippi at Alton, The old lock was both inadequate to handle the size and number of tows on the river in the early 1980s and had serious structural problems. The old 110- by 600-ft lock had an estimated maximum lockage capacity of 73 million tons per year. In 1981, 70.3 million tons passed through the old lock (total value of cargo was $14 billion). In 1982, a recession year, 68 million tons passed through, with an average delay of tows of 10 hours due to backup of traffic.

Structural problems at Lock and Dam 26 (Niemi, 1986) included lateral and vertical movement of both the lock and dam which were supported on vertically driven timber and concrete piles. The stilling basin floor (3.5 ft thick) had eroded as much as 2 to 3 ft, and voids were found in the foundation alluvium under the dam and lock guide walls. Major emergency rehabilitation work was undertaken in 1970 and 1971, and other repairs were made annually in later years. Studies indicated it would be less costly to construct a new facility that to rehabilitate the existing structures, and Melvin Price Locks and Dam were recently completed to replace Lock and Dam 26.

The Melvin Price Locks and Dam project is located 2 miles downstream from the old Lock and Dam 26 and includes one 1200-ft and one 600-ft lock. The dam has nine tainter gates (100-ft wide by 42 ft high) and an overflow dike on the west bank. Two of the gate bays are located between the locks. All spillway gates are operated at uniform opening. The 350-ft separation between the locks allows simultaneous approach and departure of tows. Total project cost was in the order of $974 million. Capacity of the new 1200-ft lock is estimated to be 94 to 100 million tons per year; capacity of both locks is estimated to be about 179 million tons per year and is expected to meet needs for the next 50 years.

11.2 Increasing Lock Capacity

Traffic capacity of locks can be increased somewhat by such measures as:

a. Improving the hydraulic system or modifying the emptying system.

b. Improving lock approaches by widening or realignment, and improving the upper approach by installing submerged dikes.

c. Instituting regulations for locking order to shorten lockage time. That is, passing a specified number of tows in one direction, then passing tows in the other direction, rather than locking tows through in order of arrival.

d. Establishing hours for locking recreational boats, or constructing a recreation boat lock.

e. Using helper boats to move unpowered barges.

f. Requiring that large tows have bow thrusters.

Major increase in lock capacity can be realized only by providing additional lock chamber space which can be done by:

a. Lengthening existing locks.
b. Replacing existing locks with larger locks.
c. Constructing additional locks.

11.3 Need for Innovations in Lock Design

The need for additional or replacement locks at many Corps projects becomes more critical each year, and construction costs have escalated dramatically, partly because replacement locks are larger than the structures being replaced. The cost of a 600-ft lock and dam on the Arkansas River in the 1960s was in the order of $10 million. A similar lock and dam on the Red River, completed in December 1994, cost about $115 million.

Total cost of the recently completed Melvin Price Locks and Dam on the Mississippi was about $970 million, but that project included one 1200- and one 600-ft lock and more spillway capacity than on the Arkansas or Red Rivers. Estimated cost of the Olmsted project now under construction on the lower Ohio River, which includes two 1200-ft locks, is in the order of $1.2 billion.

Navigation projects in the United States formerly were Federally funded. However, the Waterways Development Act of 1986 requires that funding for new locks and for major rehabilitation work be shared 50-50 by the Federal government and the Inland Waterways Trust Fund. The Trust Fund derives its monies from a tax on fuel used on the inland waterways system, currently 20 cents per gallon, and such revenues are limited. This restricts the number of replacement and rehabilitation projects that can be undertaken each year, and the backlog of critically needed work increases each year. Accordingly, the Corps of Engineers for the past few years has vigorously pursued a program seeking innovative and less costly designs to restore the aging navigation infrastructure.

11.4 Innovative Lock Design Program

The primary focus of the Corps' innovative lock design effort involves replacing conventional gravity lock chamber walls with less costly thin walls between the miter gate monoliths. At existing locks, filling and emptying culverts are located in the lock walls for all the commonly-used filling and emptying systems. The new thin-wall concept would locate the filling and emptying culverts on the floor of the lock chamber, and the intake systems could be placed in the upper miter gate sill, Figure 11.5. Vertically mounted butterfly valves are proposed for use as culvert control valves.

Because these new concepts are very different from conventional designs, the Corps has undertaken a series of model studies to investigate hydraulic performance of the new filling and emptying systems to ensure they will perform acceptably.

A model testing program has been set up at the USACE Waterways Experiment Station

(WES), Vicksburg, Mississippi, to investigate suitability of the new concepts for design of filling and emptying for new locks proposed at four sites: McAlpine Lock and Dam, Ohio River; Marmet Lock and Dam, Kanawha River; Monongahela River No. 4 Lock and Dam; and a representative lock on the Upper Mississippi.

Other new concepts involve modification of the upstream guide and guard wall designs. However, the greatest savings in construction costs comes from placing the filling and emptying system on the lock chamber floor instead of in the lock walls. About 15 percent less material would be needed for the thin wall design, but the most significant savings would be in placing concrete for the walls without having to form for the culverts and in reinforcing steel. It is likely that a roller-compacted concrete base with a cast-in-place cap and lock face could be used for the walls, Figure 11.6. Also, the wall foundation can be higher, cutting down on rock excavation. Such modifications are expected to lessen the construction period significantly.

Winfield Locks and Dam, Kanawha River. Some of the innovative design concepts are included in new twin 110- by 800-ft locks now under construction at Winfield, on the Kanawha River. The old twin locks at Winfield are the busiest locks on the inland waterways system, with over 20,000 lockages per year. The existing locks are 56- by 360-ft and can accommodate only one modern jumbo barge of the type used to transport coal in the region. Typical coal tows are composed of five barges that must be locked through one at a time at Winfield, requiring about 3.5 hours for a single tow to pass through. Under adverse conditions, as long as five hours is required, and tows often wait 24 hours before being locked through. These delays represent a loss to shippers of about $17 million annually. The new 800-ft locks will be capable of passing a 9-barge tow in a single lockage.

The upstream guide wall along the shore will have wide-flange steel piles grouted into rock, with a reinforced concrete cap and skirt, instead of a continuous sheetpile wall. The length of the wall will be 1000 ft, about half the usual length, and the remaining length will have the bank sloped back and riprapped.

The upstream guard wall will have half as many concrete-filled sheet pile cells as normally used, doubling the opening between cells to about 105 ft. There will be no pile arcs between the cells, and post-tensioned cap beams will be used, rather than reinforced concrete.

These modifications of the upstream approach walls are estimated to have reduced the cost of that work by more than one-third, or by about $5 million.

The first stage contract for construction of the cofferdam was completed in 1991. The contract for construction of the new lock and a 100-ft wide spillway bay between the old and new locks was awarded in May 1994. Pouring concrete began in April, 1995, and the lock is scheduled to begin operation in spring, 1997.

Modeling program. The modeling program currently underway at WES is set up in two phases to make the best use of available time, facilities, and manpower. Phase 1 testing began in March 1995. Model components and a lock facility needed for Phase 2 testing were completed in late 1995, and testing has been initiated.

- Phase 1 involves testing intake models to investigate site-specific intake and approach conditions since this is likely to be one of the most difficult design features of the new filling and emptying design.

- Phase 2 involves testing the proposed filling and emptying designs and the lock outlets.

Intake models for McAlpine, Marmet, and Monongahela No. 4 Locks will be used to identify any undesirable flow patterns in the approach areas to the locks, such as strong vortices or concentrated flows, and to refine the intake designs if improvements are needed. Intakes located in the miter gate sill are particularly susceptible to these types of flow conditions. In addition, the performance of the proposed intake and trashrack will be investigated, and velocities in the intake area will be measured to help evaluate effects on tows in the area.

Testing of two filling and emptying models began in the summer of 1995. The first model was used to develop a filling and emptying system for McAlpine, Marmet, and Monongahela No. 4 since proposed designs and project features are similar for these three locks. The second filling and emptying model will be for the Upper Mississippi lock. Model testing of the filling and emptying systems will include determining optimum location of culvert ports and the need for baffles to deflect jets from the ports and reduce hawser stresses; evaluating flow distribution in the lock chamber with free tow drift patterns, measurement of longitudinal and transverse hawser forces, and observation of surface currents. Different valve operations and associated filling and emptying times will be tested, and average pressure measurements will be obtained throughout the system. Performance of the lock outlets will be studied.

Tests initiated on the McAlpine intake model in March 1995 are complete. Preliminary results indicate that it may be desirable to use extensions on ports in the laterals to better direct jets issuing from the ports perpendicularly to the culverts; to use baffles along the walls and centerline of the lock to redirect the jets and reduce hawser stresses; and to relocate the intake ports from the miter gate sill to the approach walls (with externally mounted butterfly valves) to reduce vortex problems.

Testing of the Marmet intake model and the McAlpine filling and emptying system was scheduled to be completed in late 1995.

<u>**Marmet Lock and Dam, Kanawha River**</u>. Marmet Lock and Dam is next upstream from the Winfield project. The same upstream approach wall modifications adopted for Winfield will be used at Marmet. In addition, the new filling and emptying system concept with culverts on the lock floor is expected to result in significant savings. It is also proposed to eliminate traditional vertical lift gates for emergency closure and the low-sill passage for use by emergency craft if the upper pool is lost. This will permit the upper gate sill to be raised about 28 ft, reducing cost of the miter gates and the cost of dredging in the upstream lock approach.

It is estimated that the new Marmet Lock would cost in the order of $243 million if traditional design criteria are used. It is expected this cost can be reduced by about $50 million (20 percent) if innovative design concepts are adopted.

11-5 Other Innovative Concepts

Schmidgall (1995) has suggested two other areas were innovative design could enhance lock operation:

a. Model tests and prototype operation of locks with elaborate bottom longitudinal filling and emptying systems have shown such locks can be operated satisfactorily with valve opening times of one minute. Schmidgall suggests that lock filling time could be shortened and the low pressure problems downstream of the filling valve at high-lift locks could be minimized if the valve opening time were reduced to 15 or 10 seconds. With such a fast operating speed, the valves would quickly pass through the partial gate opening settings that create negative pressures before flow momentum has stabilized sufficiently to cause the low pressure problems.

b. An improved tow haulage system could significantly shorten the time required for double lockages. Most systems now in use were not installed at the time the locks were constructed, but were added later. These systems, which are typically cable, pulley, and winch systems are located on top of lock walls and interfere with miter gate operation. Double lockage times could be significantly reduced if the unpowered half of a tow could be pulled out of the lock chamber and secured beyond the lock long enough for the powered half to lock through and reattach to the unpowered half.

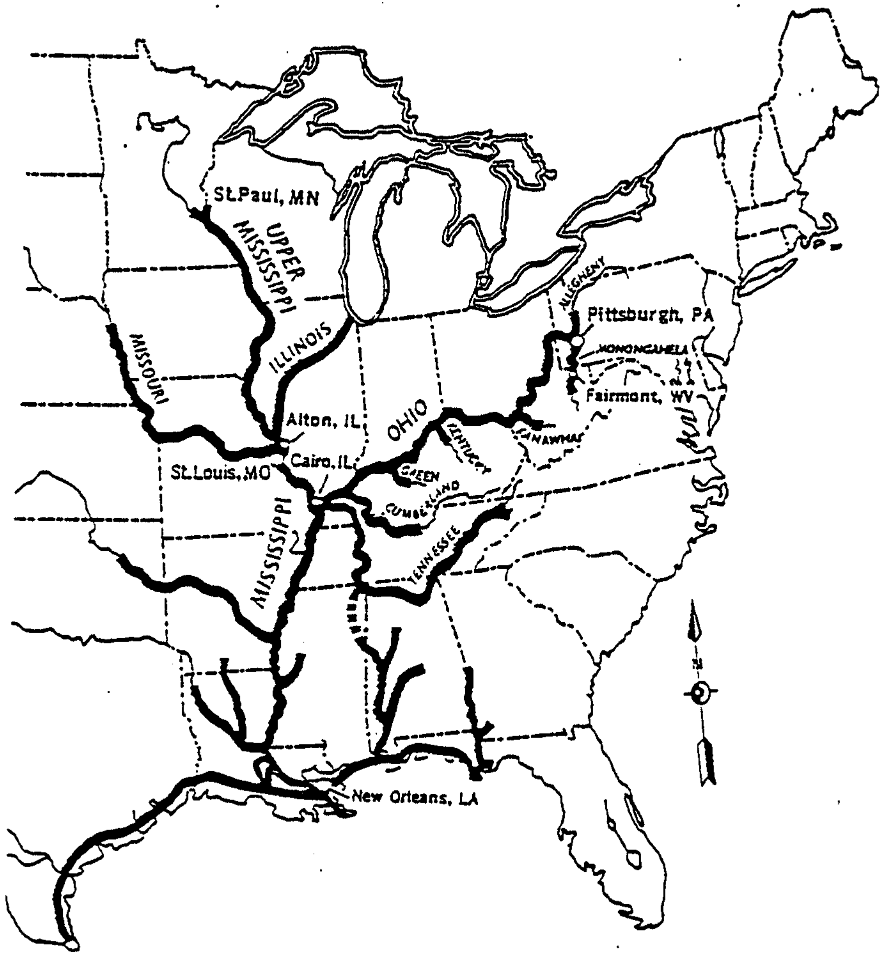

Figure 11.1, Upper Mississippi and Ohio River Navigation Systems and Connecting Waterways (Corps of Engineers).

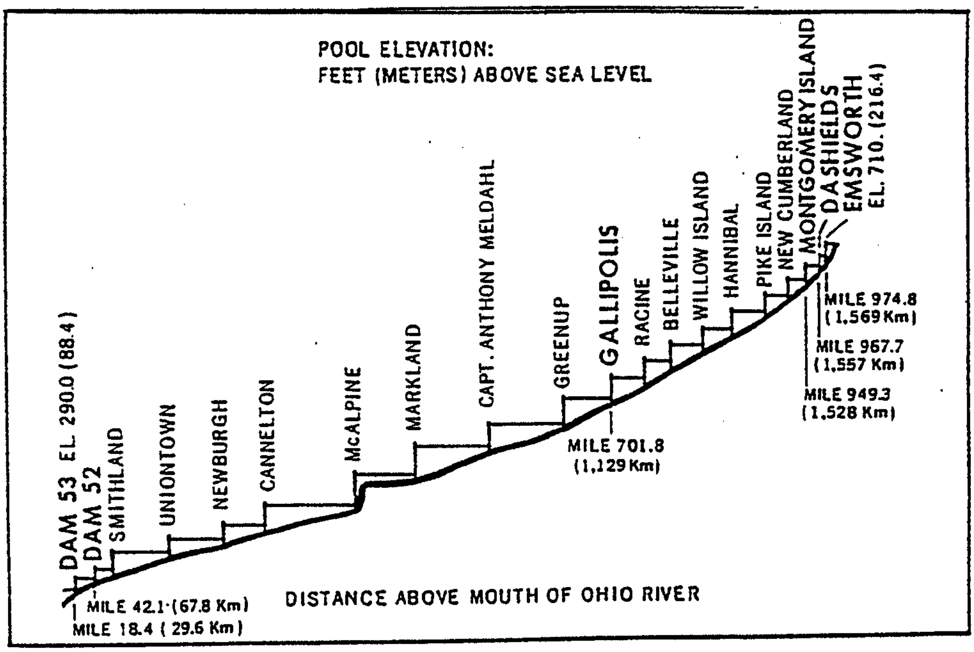

Figure 11.2, Profile of Ohio River Navigation Pools (Corps of Engineers).

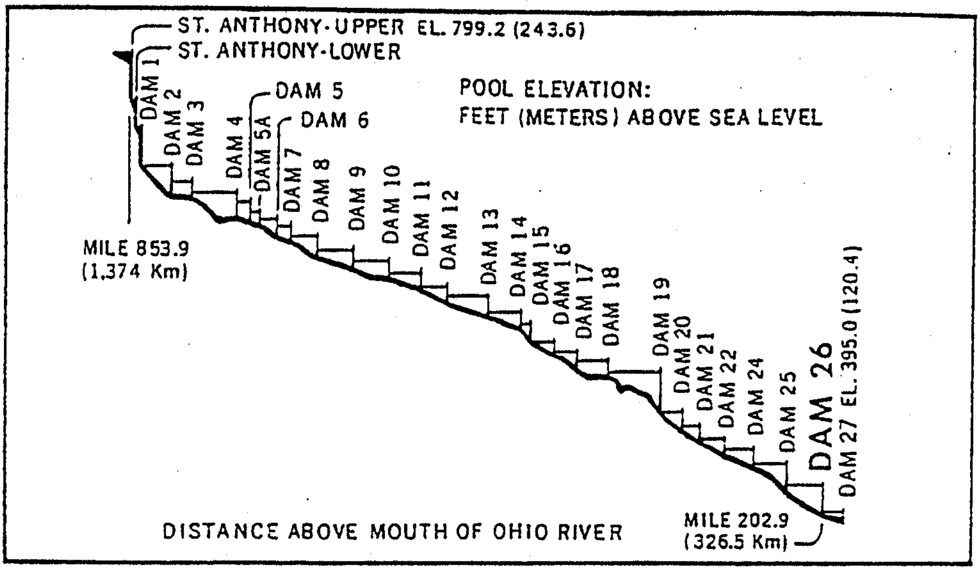

Figure 11.3, Profile of Upper Mississippi Navigation Pools (Corps of Engineers).

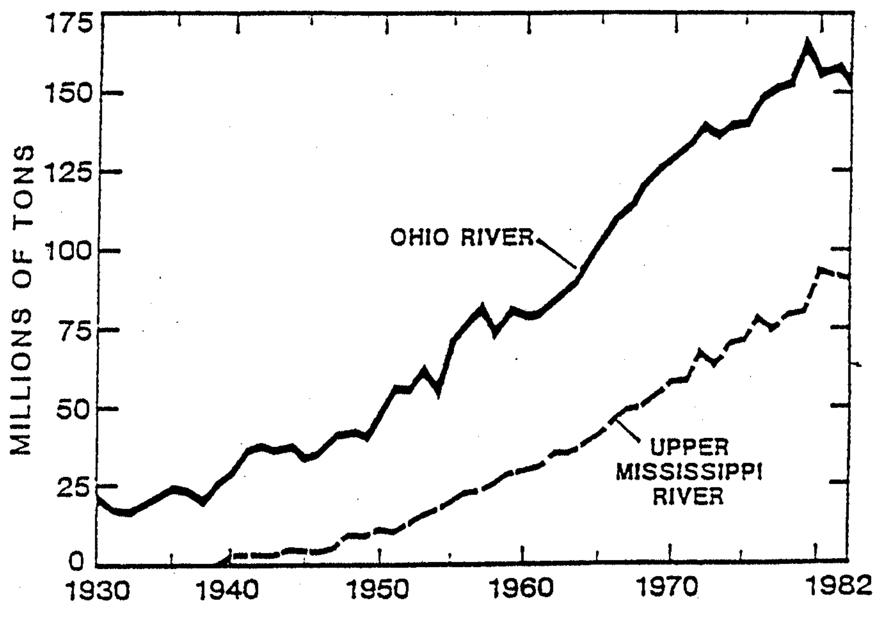

Figure 11.4, Growth of Waterborne Commerce, Ohio and Upper Mississippi Rivers 1930 - 1982. (Corps of Engineers)

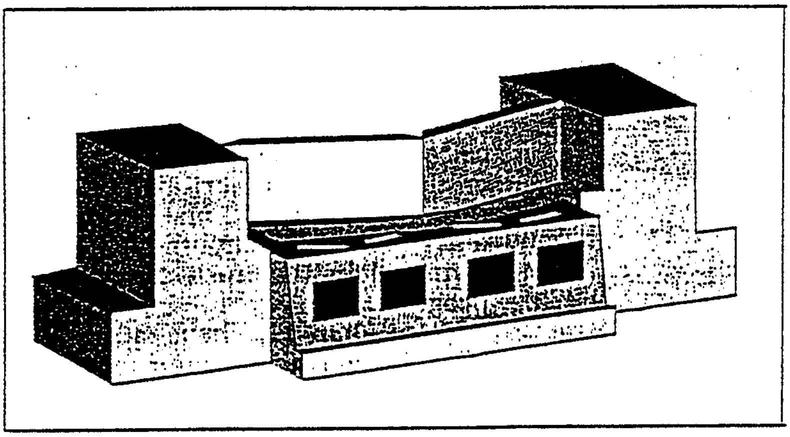

Figure 11.5, Intakes in Upper Miter Gate Sill.

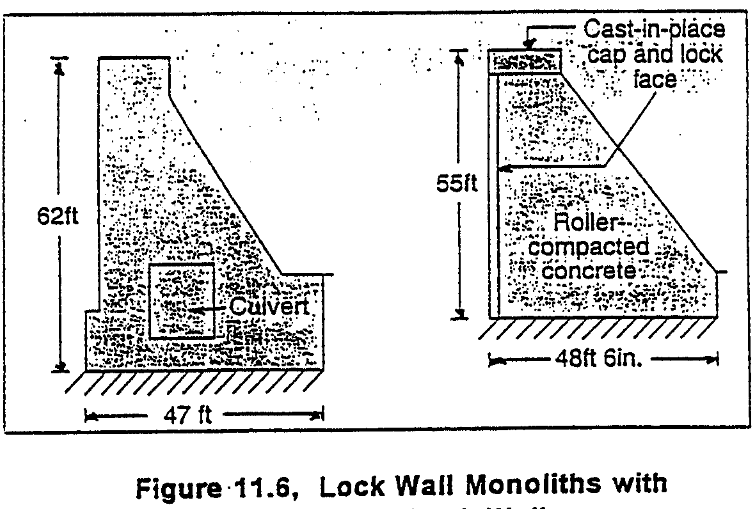

Figure 11.6, Lock Wall Monoliths with Culverts in Lock Wall and on Floor of Lock Chamber.